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REVIEW ARTICLE

Ultrasonography in Assessing Oropharyngeal Dysphagia

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Ultrasonography, a portable, noninvasive, and radiation-free technique, had been applied for assessment of oropharyngeal swallowing function for decades. The most common application is for observing the tongue, larynx, and hyoid-bone movement by B-mode ultrasonography. Although some studies describing techniques of ultrasonography have been published, its clinical application is still not well known. Other methods such as M-mode ultrasonography, Doppler ultrasonography, three-dimensional reconstruction, or pixel analysis had been reported without promising results. The techniques of ultrasonography examination of the tongue and larynx/hyoid movement are introduced in this work; in addition, a brief review about the methods and application of ultrasonography in assessing swallowing function in different groups of patients had been described. Ultrasonography, instead of a substitution of videofluoroscopic swallowing study (VFSS), may be able to complement VFSS as a rapid examination tool for screening and for follow-up of swallowing function. Further large-scale quantitative analyses that provide diagnostic value and correlation with functional outcome are mandatory.

Introduction

Oropharyngeal dysphagia is a common scenario of many neurological disorders such as stroke, traumatic brain injury, Parkinsonism, congenital or acquired neuromuscular diseases, as well as some gastrointestinal and cardiopulmonary diseases, such as gastroesophageal reflux and chronic obstructive pulmonary disease [1—9]. The

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cricopharyngeal muscle dysfunction in the former and the incoordination between breathing and swallowing in the latter may be the cause of dysphagia, although the exact mechanism is unknown [6–9]. It also occurs frequently after invasive procedures such as thoracic surgery, endotracheal intubation, or tracheostomy [10–15]. Dysphagia may result in malnutrition, dehydration, aspiration pneumonia, and even death [3,4].

The oral and pharyngeal processes of swallowing are complicated. It involves bolus formation, oral transportation, elevation of the soft palate, pharyngeal muscle contraction, larynx elevation, and cricopharyngeal muscle relaxation. During the oropharyngeal swallowing process, tongue movement, larynx elevation, and relaxation of cricopharyngeal muscle are three determinant factors for effective and safe swallowing [16–21].

The tongue has a vital role in oral processing of food, contributing to the oral preparatory and transit phase of swallowing [22–26]. The contact between the tongue base and the soft palate during oral holding prevents premature oral leakage [17,18,27]. To initiate swallowing, there is a sequential, wave-like tongue movement that transports the food from the anterior surface of the tongue to its base. Subsequently, a rapid elevation of the tongue base, along with approximation of posterior pharyngeal wall, propels the bolus into the pharynx [22–24]. The pressure generated by the tongue base and posterior pharyngeal wall is also essential to cricopharyngeal muscle opening [25,26].

Larynx elevation is crucial for airway protection and cricopharyngeal muscle relaxation [25,26,28]. The contact of bolus and the anterior faucial arch or vallecula triggers the swallowing reflex, a finely coordinated movement in which the thyroid cartilage approximates to the hyoid bone, the larynx elevates, the epiglottis tilts down, and the glottis closes to prevent the bolus from entering the trachea. Cricopharyngeal muscle opens subsequently, allowing the bolus to pass through [27,29–31]. Timely and adequate larynx elevation is vital throughout this process; and one of the major contributors of larynx elevation and cricopharyngeal muscle opening is the upward and forward displacement of the hyoid bone, mediated by the coordinated contraction of suprahyoid and infrahyoid muscles [25,26,28].

The videofluoroscopic swallowing study (VFSS) and fiberoptic endoscopic evaluation of swallowing (FEES) are the most commonly used objective tools for assessing the swallowing function. However, the need to transport patients and the need for radiation exposure often limit the use of VFSS [32]. The FEES is portable and has no radiation, but is invasive and less quantitative [33]. Compared with these methods, ultrasonography has the following advantages: radiation free, noninvasive, portable, and the possibility of using real food in swallowing assessments. These advantages make ultrasonography an ideal tool in screening and serial follow-up of dysphagic patients.

Previous studies have applied ultrasonography for observing the tongue, larynx, and the hyoid bone movement [34–39]. For decades, various techniques and instruments have been reported regarding the use of ultrasonography in depicting the structures and movements of the larynx or tongue [34–39]. There is still a limited clinical application, however, due in part to the lack of consensus in the role of ultrasonography in assessing swallowing function. This article attempts to provide the reader a basic understanding of the examination techniques, accuracy and reliability, and clinical applications of ultrasonography in assessment of oropharyngeal dysphagia.

Techniques and applications of ultrasonographic assessment of oropharyngeal swallowing

Tongue movement and larynx elevation are among one of the most important parameters of swallowing function [22–26,28]. Previous studies had focused on assessment of these two parts.

Oral phase: tongue

Observation of tongue motion is the most common ultrasonography application in swallowing evaluation. Previous studies have applied B-mode, M-mode, Doppler ultrasonography, three-dimensional (3D) reconstruction, and other techniques in assessing tongue movement [34–36,40–44]. Either a sector or a curvilinear transducer, 3–7 MHz in frequency [45], had been used to observe the soft-tissue structure, texture or hemodynamic changes of the tongue, and bolus processing in the oral stage of swallowing. In the ultrasonographic imaging of the tongue, the midsagittal view is the most commonly used. The transducer is placed submentally, vertical to the skin, along the midline of the long axis of the tongue (Fig. 1). Under the B-mode ultrasonography, the tongue surface appears as a convex bright echogenic line, representing the interface of tongue muscle and intraoral air. The musculature of the tongue (genioglossus muscle) and mouth floor (geniohyoid and mylohyoid muscles) can be clearly depicted [34–36,40,41,43,46–48]. The palate can be seen only when the tongue or bolus contacts it. For dynamic analysis, the ultrasonography is connected to a video recorder and the images can be analyzed frame by frame.

Shawker et al [34,35] first applied hand-held B-mode ultrasonography for observing the motor sequences of the tongue movement while swallowing 5 mL of water. They measured the midtongue thickness at the bisection of the ultrasonography beam (Fig. 2). This technique required manual frame-by-frame analysis. They also observed that the patient with hypoglossal nerve palsy had an increased midtongue thickness at both resting and while swallowing with prolonged sequential swallowing movement, when compared with that of eight normal participants.

Stone and Shawker [36] recorded anterior–posterior and superior–inferior movement in the midsagittal view with a fixed stainless metal pellet to the anterior third of tongue surface. They found that the major tongue movement (the largest amplitude) correlates with the propulsion of the bolus into the pharynx and with the elevation of the hyoid bone. The use of a pellet enables a clear depiction of movement at a specific point, but it may be oversimplified to represent the complex coordinated movement of the tongue.

Wein et al [49] reported a temporal reconstruction approach of ultrasonographic imaging of the tongue. In

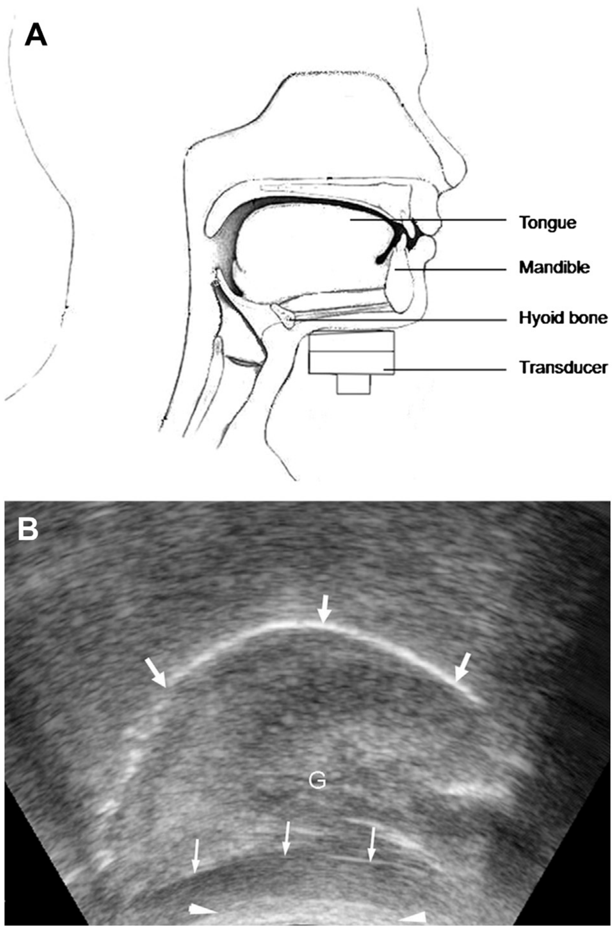

Fig. 1 (A) Anatomy of the oral cavity and position of the sector transducer. (B) Submental midsagittal ultrasonography image showing the genioglossus muscle (G), geniohyoid (arrows), and mylohyoid muscles (arrowheads) at the mouth floor. The tongue surface appears as hyperechoic lines (broad arrows).

Fig. 2 Calculation of tongue thickness: the dashed lines "a" and "b" indicate the border of the ultrasonographic beam. The dashed line "c" is the bisection of the ultrasonographic beam, in which the midtongue thickness is measured (two-end arrow).

these methods, the superior tongue surface was marked image by image, the surface contours were sampled in temporal order (every 0.04 seconds), and reconstructed to show an integrated photo, which can represent the total act of tongue surface during swallowing in one single image. The authors reported characteristics for differentiating between pathological and physiological movements, including degree of rigidity, the succession of movement, and the coordination of movement. The interpretation of these results is descriptive and subjective, however.

Yang et al [38] had developed a descriptive scoring system for ultrasonographic observation of the oral stage of swallowing, as well as for items including tongue musculature, bolus control, initiation, and coordination of tongue and hyoid movement. They observed significantly lower scores in 32 malnourished children with long-term neurological disability and severe feeding difficulties, when compared with 27 normal children. It indicated that ultrasonography can detect impaired tongue movement in oropharyngeal dysphagia.

To facilitate automatic processing of images, band M-mode ultrasonography had been used simultaneously to assess vertical movement of the tongue through a fixed scan line [40,41,43]. The position of the tongue surface on the M-mode image was extracted by a graphic program. The duration, range, and speed of vertical movement at the scan line can then be calculated (Fig. 3). de Wijk et al trained the participants to hold the transducer by themselves. However, to achieve reliable measurements by M-mode ultrasonography, stabilization equipment is required [41]. Peng et al proposed a cushion-scanning technique for fixing the patient and the transducer [40].

Doppler ultrasonography had been applied in analyzing the hemodynamic changes during swallowing and tongue contraction [50—52]. The technique identified changes in lingual blood flow during different swallowing tasks and during different degrees of muscle contraction. Some scholars use 3D reconstruction techniques to provide volumetric measures of the tongue and soft tissues at the mouth floor [53]. However, their clinical application is still limited.

In a recent study, Van Den Engel-Hoek et al [44] used intraoral ultrasonography (linear, 14—5 MHz) and transversely placed submental ultrasonography (linear, 10—5 MHz) to observe the muscle thickness and echo intensity of the tongue and submental muscle (digastric and geniohyoid muscles), respectively (Fig. 4). They found increased thickness of the tongue and increased echogenicity of submental muscles in the five patients with Duchenne muscular dystrophy (DMD), as compared with 53 healthy participants, and suggested that it is a possible way to differentiate between the healthy individuals and DMD patients.

Yabunaka et al [47] used B- and M-mode ultrasonography simultaneously to evaluate movement of the geniohyoid muscle. The curilinear transducer (5 MHz) was placed longitudinally along the submental region. The duration and range of geniohyoid muscle bulging upward during swallowing at a specific scan line can be measured quantitatively. They found significant differences between genders in each of the three age groups, although the clinical significance is unknown.

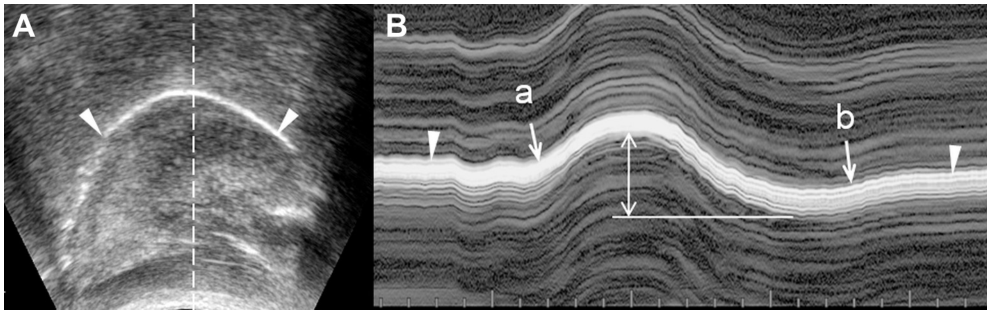

Fig. 3 (A) B-mode ultrasonographic imaging of the tongue. M-mode ultrasonography was extracted at a vertical scan line (dashed line). The arrowheads indicate the tongue surface. (B) M-mode ultrasonography. Point a indicates the onset of tongue movement, while point b indicates the return of tongue to its resting position. The two-end arrow indicates the peak-to-peak amplitude of tongue movement at the scan line.

Pharyngeal phase: larynx

The application of ultrasonography in assessing the pharyngeal phase of swallowing is less common compared with that in assessing the oral phase. Previous studies have used ultrasonography for observing lateral pharyngeal wall motion, thyroid—hyoid bone approximation, and hyoid bone displacement [39,48,54—58]. However, the vallecula and pyriform sinus could not be assessed by ultrasonography. A curvilinear transducer with 3—10 MHz [45] is commonly used. Shawker et al [34,35] was the first person to use ultrasonography in evaluating the larynx movement, and used submental B-mode ultrasonography to observe the tongue movement and found that the hyoid bone is visible when it elevates and enters the scanning ultrasound beam. Despite the early findings by Shawker et al [34,35], there had been limited progress in applying ultrasonography in assessing the pharyngeal phase since then.

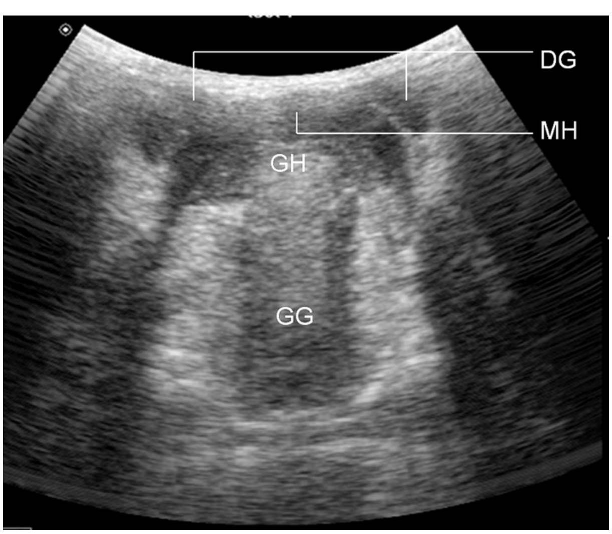

Fig. 4 Transverse view of submental ultrasonography. The mylohyoid muscle (MH) is a thin layer of tissue. Below are the geniohyoid (GH) and genioglossus (GG) muscles; the cross-section of anterior belly of the digastric muscle (DG) appears as an hypoechoic, oval-shaped structure.

Miller and Watkin [54] used B + M-mode ultrasonography to assess lateral pharyngeal wall motion for testing the effects of specific swallowing maneuvers. A curvilinear transducer (5 MHz) was placed vertically behind the mandible ramus. The duration and displacement of pharyngeal wall movement during different swallowing maneuvers (supraglottic, super-supraglottic, and Mendelsohn maneuvers) and different swallowing volume were measured. They found no significant difference of pharyngeal wall displacement across different swallowing maneuver and volume, but there is significantly longer duration of displacement in the super-supraglottic and Mendelsohn maneuvers. In this preliminary study, it showed that ultrasonography could be a possible method to evaluate for efficacy of different therapeutic maneuvers or be used as a biofeedback training method.

Kuhl et al [39] and Huang et al [55] used B-mode ultrasonography to measure hyoid—larynx approximation, using the result as a parameter to estimate larynx elevation. The former used a 7.5-MHz linear transducer and the latter used a 10-MHz curvilinear one. The transducer was placed at the midline along the long axis of the throat (Fig. 5). The thyroid cartilage and the hyoid bone can be visualized as two distinct hyperechoic plaques with acoustic shadows. Images were recorded and analyzed frame by frame and the approximation of thyroid cartilage and the hyoid bone can be calculated. In 40 stroke patients and 15 normal adults, Huang et al [55] found that the thyroid—larynx approximation of the dysphagic stroke group was significantly less than that of the nondysphagic stroke group and the normal group. They also reported similar measurement results between ultrasonography and VFSS in 10 of the patients.

Regarding the measurement of hyoid bone displacement, Chi-Fishman and Sonies [58] used a custom-made transducer holder assembly to fix an annular array transducer (3.5—6 MHz). In this method, the hyoid bone movement during the whole swallowing process can be well observed. They successfully calculated the maximal distance, velocity, and duration of the hyoid bone movement at different swallowing tasks. Later, Yabunaka et al [57] applied hand-held ultrasonography to observe the hyoid bone movement during swallowing process. The curvilinear transducer (3.5—7 MHz) was placed longitudinally in front of the hyoid bone. By tracing the position of the hyoid bone during swallowing frame by frame, the trajectory of hyoid

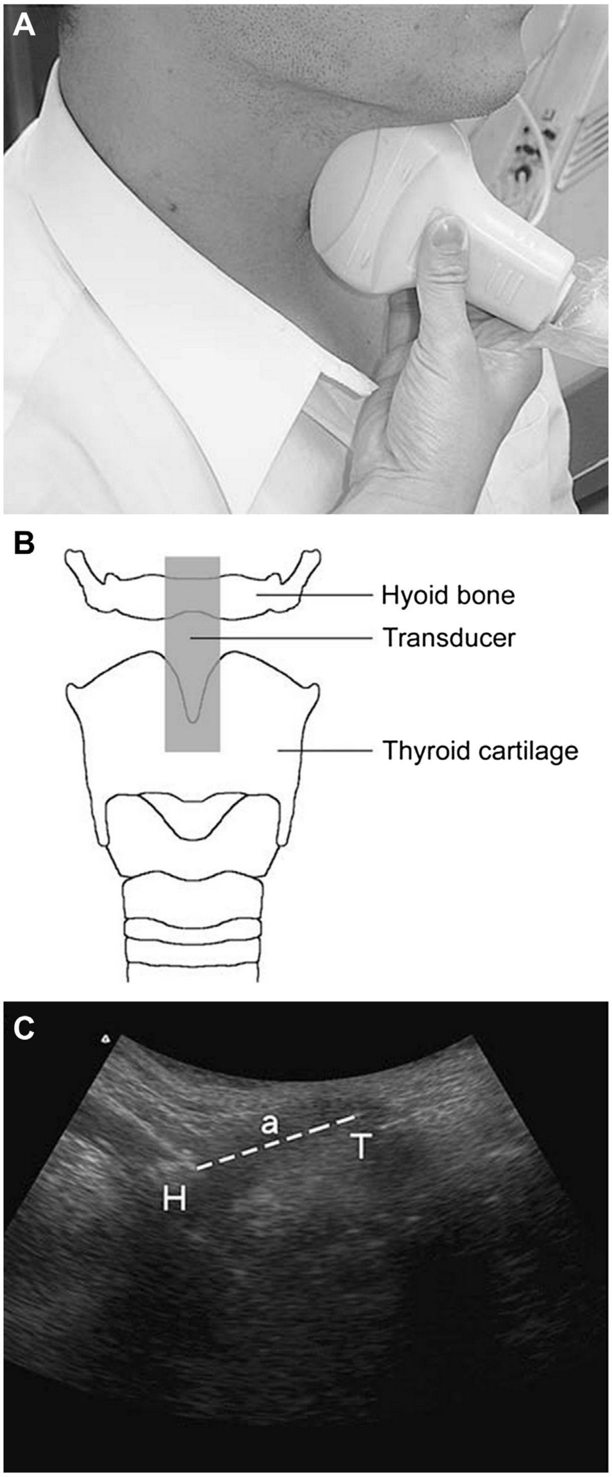

Fig. 5 (A) The positioning of the transducer and (B) the anatomy of examination of thyroid—hyoid approximation. (C) Ultrasonography image showing the hyoid bone (H) and thyroid cartilage (T); the dashed line is the distance between the thyroid cartilage and the hyoid bone.

bone movement was depicted. Both these studies used the resting position of the hyoid bone as a pair of coordinates to calculate the displacement of the hyoid bone.

In our recent study [48], a larger transducer is manually placed submentally, with the posterior border of the transducer covering the hyoid bone (Fig. 6A). In this way, the tongue and the hyoid bone can be simultaneously visualized throughout the swallowing process. The hyoid bone and the mandible are identified as two hyperechoic areas with posterior acoustic shadows. At the mouth floor are suprahyoid muscles (geniohyoid and mylohyoid muscles) (Fig. 6B). We used the mandible as the reference point to calculate the hyoid bone displacement. Using a two-axis coordinate system, the position of the hyoid bone in relation to the mandible in each frame was represented as coordinate pairs. The distance between two coordinates before and during swallowing denotes the hyoid bone displacement (Fig. 7). Using the mandible as the reference point, one can eliminate the measurement error caused by transducer translation to skin during swallowing.

To increase the clinical significance of ultrasonography in assessing oropharyngeal dysphagia, we further defined the diagnostic cut-off values for severe dysphagia that may necessitate tube feeding [48]. In 60 stroke patients (30 tube feeding dependent and 30 on regular oral intake) and 30 healthy controls, we found that those with a tongue

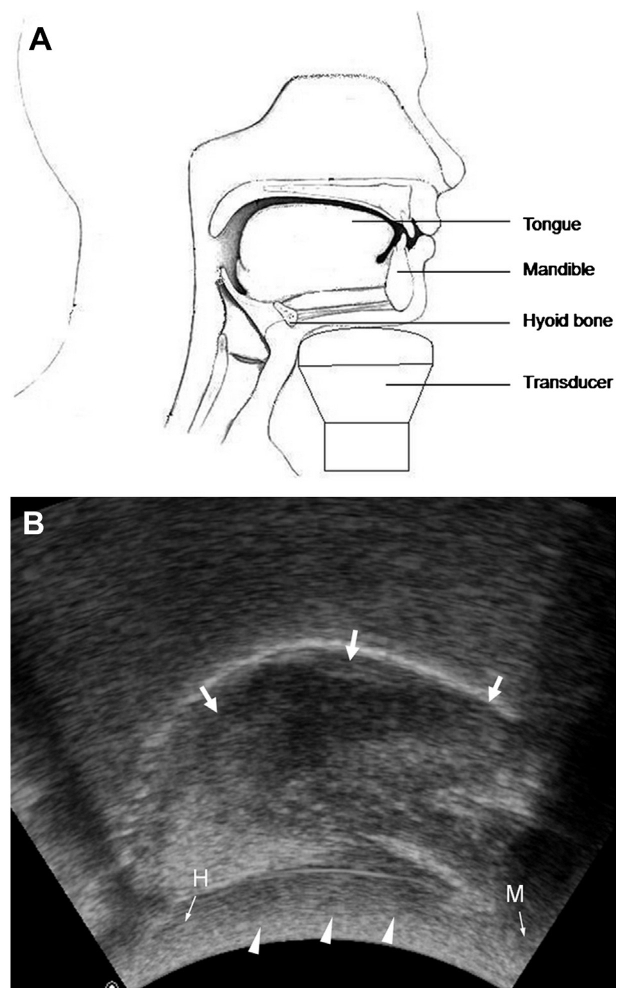

Fig. 6 (A) Anatomy of the oral cavity and position of the curvilinear transducer. (B) Submental midsagittal ultrasonography image showing the hyoid bone (H) and the mandible (M) and muscles at the mouth floor (arrowheads). The tongue surface appears as hyperechoic lines (arrows).

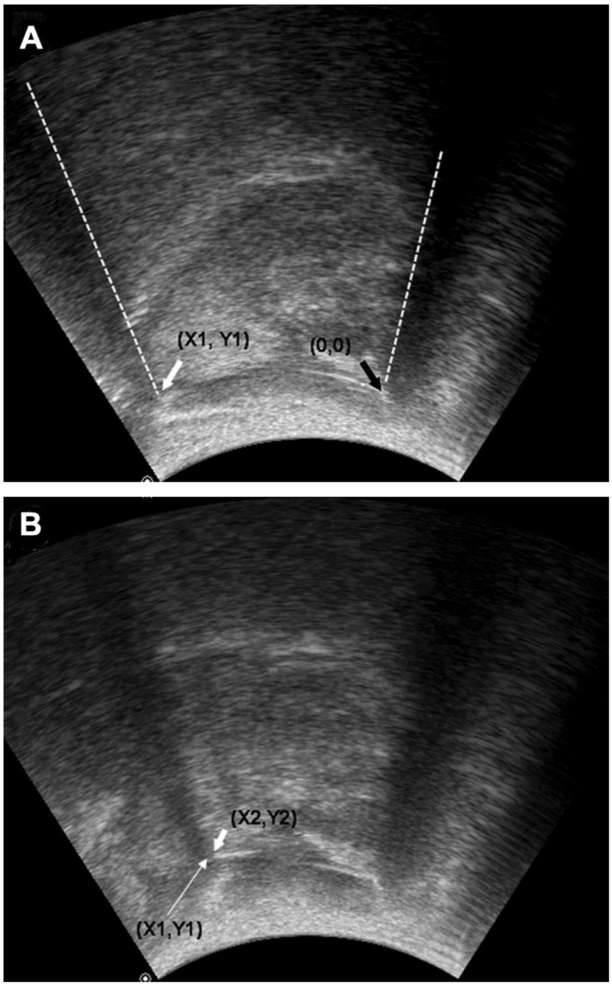

Fig. 7 Calculation of the hyoid bone displacement. (A) The position of the mandible (black arrow) was used as the reference point, and the resting position of the hyoid bone (white arrow) was designated as a pair of coordinates (X_1, Y_1). (B) During swallowing, the hyoid bone moves upward and forward into a new position (arrow) designated by X_2, Y_2, with the mandible as the reference point. The distance between the two coordinates before and after swallowing denotes the hyoid bone displacement (thin arrow).

thickness change of less than 1.0 cm and hyoid bone displacement of less than 1.5 cm were likely to be tube feeding (sensitivity 70–73% and specificity 67%). It enabled ultrasonography to be used in screening for high-risk patients with severely impaired swallowing function in a more objective manner. Further large-scale studies are required to verify the diagnostic accuracy of submental ultrasonography and to determine whether the results correlate with aspiration rate.

Direct measurement of larynx elevation by ultrasonography is technically more difficult. To calculate absolute displacement, one needs to identify a stationary reference point and what is lacking in assessing larynx elevation, because the nearby structures in the same ultrasonography view often move together during the process of swallowing. The measurement of absolute displacement of hyoid bone may be a better method as the mandible can be used as the reference point. Occasionally, it is difficult in patients with prominent thyroid cartilage. Placing a water balloon in front of the transducer may increase the image quality.

Role of ultrasonography in swallowing function assessment

Although considered the gold standard of assessing oropharyngeal dysphagia, VFSS has several limitations. First, the patients need to be transported to an examination room with specific equipment. The radiation exposure also limits the time of VFSS examination, and makes it less likely to be a tool for serial follow-ups. In addition, whether the results of VFSS can reflect the patient's swallowing function in real condition is doubted, because the texture and taste of barium meal is very different from food.

Ultrasonography is portable and can be used at the bedside for encumbered patients. It is noninvasive and has no radiation. Another advantage of ultrasonographic examination is the possibility of the use of real food in swallowing assessments, which facilitates a more physiological evaluation of the swallowing function. Finally, other abnormalities in the oral stage, such as inadequate bolus control, premature oral leakage, impaired tongue propulsion, and multiple swallowing, can be observed using submental ultrasonography. At this point, ultrasonography is no substitution for VFSS. VFSS provides a comprehensive evaluation of the physiology and anatomy of both the oral and pharyngeal stages of swallowing, while ultrasonography could complement VFSS as a rapid examination tool for screening high-risk patients and for follow-up of swallowing function.

Conclusion

Ultrasonography, a portable, noninvasive, and radiation-free technique, provides a readily accessible method for evaluating both the oral and pharyngeal phases of swallowing. Previous studies, although limited, seem to indicate that the measurement of larynx elevation, hyoid bone movement, and tongue movement by ultrasonography could be a possible method for evaluating oropharyngeal dysphagia. It can provide additional information to help clinicians obtain the whole picture of the swallowing function of a patient. However, more high-quality, large-scale clinical studies are needed to provide the diagnostic cut-off value, functional correlation, and prognostic data of swallowing assessment by ultrasonography.

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